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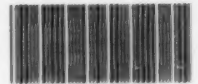
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TP 9913 E

**DEVELOPMENT OF AN AUTOMOBILE SIMULATOR
FOR THE ASSESSMENT AND TRAINING OF
DISABLED DRIVERS**

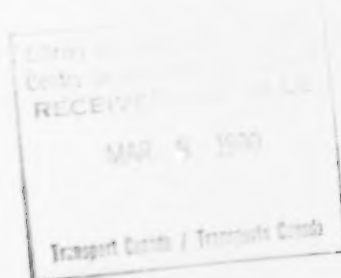
Prepared for:

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Transport Canada

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Un sommaire en français de ce rapport est inclus avant la Table des matières.

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16. Abstract The purpose of this project was to develop a prototype of a relatively low-cost, high-fidelity, microprocessor-based automobile simulator for the assessment and training of disabled drivers. The essential element was the application of current microprocessor technology with appropriate software development to develop the simulator system consisting of the cabin, computer system, vehicle model software, visual display, force feel and acoustic modules. The development was taken to the point of a proof-of-concept working simulator. This system was conceived and built in a way that future improvements and enhancements are possible without having to alter the basic system configuration. The resulting prototype confirmed the validity of the technical approach. The results indicate that further development of the visual, force feel, assessment and training systems, in addition to a more "user-friendly" instructor's facility, are required to achieve a commercially viable product.					
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16. Résumé Le but de ce projet était de réaliser un prototype de simulateur de conduite automobile piloté par microprocesseur qui allierait un coût relativement bas et un haut degré de réalisme et qui servirait à la rééducation des conducteurs âgés ou handicapés. L'essentiel de la recherche visait l'application des derniers perfectionnements de la microélectronique et la création d'un logiciel spécialisé en vue de produire un simulateur de conduite automobile composé des éléments suivants: module cabine, module ordinateur, logiciel de modélisation de véhicule, module de visualisation et module dynamométrique et acoustique. Le processus de R&D en est à l'étape du prototype de validation de principe. Le principe qui sous-tend le concept choisi permet l'amélioration du système sans qu'il soit nécessaire d'en modifier l'architecture de base. Le prototype issu de cette approche confirme la validité du principe technique et met en évidence la nécessité: a) d'améliorer le module de visualisation, le module dynamométrique et les modules d'évaluation et de rééducation et, b) d'accroître la convivialité du module d'instruction pour que le produit soit commercialement viable.					
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SUMMARY

Simulators, in general, provide a controlled environment for the assessment or training of operators of complex equipment. In most current applications, the use of simulators is restricted to very costly equipment such as civil or military aircraft or nuclear power stations. Advances in microprocessor and computer graphics technology have made it feasible to address other areas where less costly equipment is used such as in general aviation or, in the case of this project, automobile transportation.

The objective of the project was to develop a prototype of a low-cost, high-fidelity, microprocessor - based, automobile simulator suited for assessment and training of disabled and elderly drivers. Because simulators in general are economically feasible when they cost less to purchase and operate than the equipment they simulate (e.g. automobiles), the main challenge of the project was to rigorously maintain system cost effectiveness while providing the required degree of simulation fidelity.

The methodology of the R&D project work was based on low-cost technological approaches developed by Concordia University in the course of their light aircraft flight simulator development.

The project resulted in a proof-of-concept automobile simulator system. The system, conceived as a modular one, consists of a cabin module, a computer module, a vehicle model software module, a visual display module, a force-feel module and acoustic module. The cabin module is based on actual car hardware and has all the normal instrumentation and controls. The computer module includes computer hardware, system software and instructor facilities software. The vehicle model software module determines vehicle movements, as well as the engine parameters, in response to the driver control inputs. The fully interactive visual display module, including both hardware and software, generates the car simulator visual cues in response to the vehicle model position outputs. The force-feel and acoustic modules generate realistic control feel forces and acoustic cues in response to the vehicle model outputs.

The original project goals were generally achieved, although in a somewhat reduced form as a result of budgetary restrictions. The less than hoped for level of developments encompass the areas of visual system, the force-feel system, the instructor facilities, and the assessment/training protocols. However, the simulator system was conceived and built in such a way that future expansions and improvements are possible without having to change the basic hardware and software structures of the system.

In order to transform the existing 'proof-of-concept' device into a commercially viable system, the recommendations are that further R&D work be carried out in the following areas:

- (i) the visual and
- (ii) force-feel systems,
- (iii) instructor facilities,
- (iv) assessment system, and the
- (v) training system.

SOMMAIRE

En général, les simulateurs ont pour fonction de créer un environnement contrôlé afin de faciliter l'évaluation ou la formation des opérateurs de matériels complexes. Jusqu'à tout récemment, cette technologie était appliquée à la simulation des matériels très coûteux tels que les aéronefs civils ou militaires ou encore les centrales nucléaires; mais grâce aux progrès de la microélectronique et la technologie infographique, il est maintenant possible d'utiliser la simulation dans d'autres champs d'applications, pour des matériels moins coûteux, notamment les domaines de l'aviation générale et du transport automobile.

L'objectif de ce projet était de réaliser un prototype de simulateur de conduite automobile commandé par microprocesseur qui soit à la fois économique et à grand degré de réalisme, et qui convienne à l'évaluation et à la rééducation des conducteurs âgés ou handicapés. Comme il est d'ores et déjà établi que l'emploi de simulateurs est rentable lorsque leur coût d'achat et d'exploitation est inférieur à celui du matériel dont ils reproduisent le fonctionnement (par exemple une automobile), le principal défi était de maintenir un rapport coût/efficacité optimal tout en obtenant le degré de réalisme souhaité.

La recherche a tiré parti des solutions technologiques économiques mises au point par le groupe de recherche de l'Université Concordia sur les simulateurs de vol pour petits avions.

Le projet a débouché sur la réalisation d'un prototype de validation de principe. Ce système, de conception modulaire, est constitué par un module cabine, un module ordinateur, un logiciel de modélisation de véhicule, un module de visualisation, un module dynamométrique et un module acoustique. Le module cabine simule un modèle de voiture réel, avec tous les instruments de commande et de contrôle usuels. Le module ordinateur comprend les composants matériel et logiciel ainsi que le logiciel d'instruction. Le logiciel de modélisation de véhicule règle les mouvements du véhicule ainsi que les paramètres de fonctionnement du moteur selon les commandes parvenant de la cabine. Le module de visualisation interactif, qui comprend un poste infographique et un logiciel, produit les séquences visuelles correspondant aux données de position générées par le logiciel de modélisation du véhicule. Les modules dynamométrique et acoustique produisent des effets dynamométriques et acoustiques réalistes correspondant aux données du logiciel de modélisation du véhicule.

Les objectifs initiaux du projet ont tous été réalisés, mais il demeure qu'ils l'ont été de façon relativement sommaire, à cause des compressions budgétaires intervenues en cours de route. Il en a résulté un certain nombre de compromis, notamment à l'égard du module de visualisation, du module dynamométrique, du module d'instruction et des protocoles d'évaluation/rééducation. Il convient toutefois de préciser que le simulateur a été conçu pour en faciliter l'extension et l'amélioration sans qu'on soit obligé de modifier sa configuration matérielle et ses logiciels de base.

Pour que le prototype de validation de principe existant puisse être transformé en un simulateur commercialement viable, on recommande d'axer les travaux complémentaires de R&D sur les composants suivants:

- (i) module de visualisation,
- (ii) module de dynamométrique,
- (iii) module d'instruction,
- (iv) module d'évaluation, et
- (v) module de rééducation.

TABLE OF CONTENTS

	Page
1. INTRODUCTION	1
2. SYSTEM DESCRIPTION	2
2.1 OVERALL SYSTEM CONFIGURATION	2
2.2 CABIN MODULE	2
2.3 COMPUTER SYSTEM MODULE	5
2.3.1 Computer Hardware	5
2.3.2 System Software	7
2.3.2.1 Hardware Interfacing	7
2.3.2.2 Communication With IRIS	7
2.3.2.3 Collision Detection	8
2.3.2.4 Crude Vehicle Model	8
2.3.2.5 Hardware Debugging Tools	9
2.3.3 Instructor Facilities Software	9
2.4 VEHICLE MODEL SOFTWARE MODULE	9
2.4.1 Model Concepts and Limitation	10
2.4.2 Model Structure	12
2.5 VISUAL DISPLAY MODULE	13
2.5.1 Visual Hardware	13
2.5.2 Visual Software	13
2.6 FORCE-FEEL MODULE	17
2.7 ACOUSTIC MODULE	18
3. SUMMARY OF RESULTS AND CONCLUSIONS	20
4. RECOMMENDATIONS FOR FUTURE WORK	21

1. INTRODUCTION

Advances in microprocessor and computer graphics technology presented the opportunity to apply the benefits of simulator technology to the area of automobile transport, which was not economically possible previously. These benefits are related to the fact that simulators provide a controlled and safe environment for operator assessment and training. The benefits include the possibility to expose the subjects to structured and repeatable assessment/training scenario or to scenarios which would be difficult or dangerous to reproduce in reality. In addition the subject performance measurements can be carried out in the comfort of a laboratory environment.

The objective of the project was to develop a prototype of a low-cost, high-fidelity, microprocessor based automobile simulator suited for assessment and training of disabled drivers in order to aid handicapped and elderly to access transportation services in Canada. Since, simulators in general are economically feasible, when they cost less to purchase and operate than the equipment they simulate (i.e. cars), the main challenge of the project was to rigorously maintain system cost effectiveness, while providing a maximum degree of simulation fidelity.

The simulator R & D work was based on low-cost technological approaches developed by Concordia University in the course of their light aircraft flight simulator development. The first year of the two-year car simulator project was used mostly for the system configuration and hardware work, while the second project year was devoted to the development and refinement of the visual software, the vehicle dynamics software and the system software. The second project period was also used to define the follow-up work.

The simulator system concepts and configuration resulted from careful blending of specification requirements, available microprocessor and visual system technology, and the market cost constraints.

2. SYSTEM DESCRIPTION

2.1 OVERALL SYSTEM CONFIGURATION

The overall view of the car simulator is shown in Fig. 1

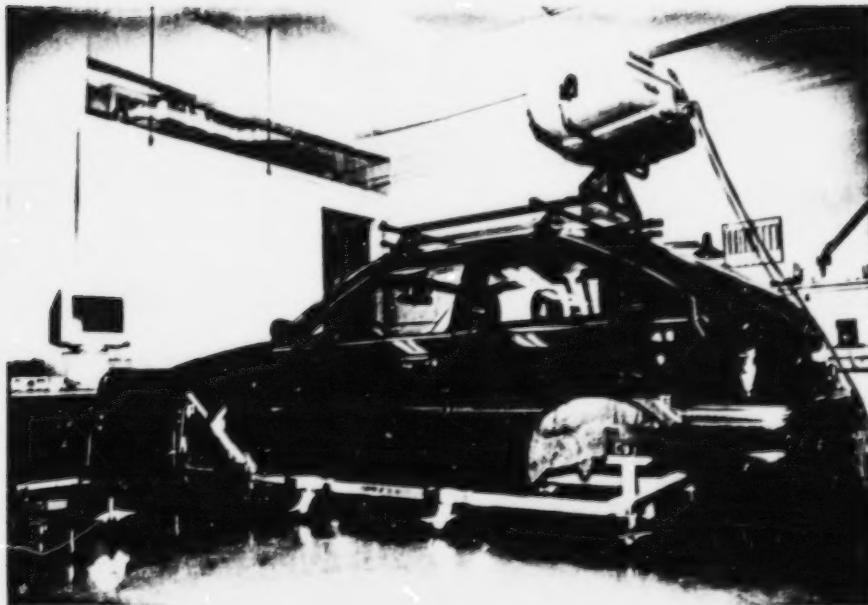


Fig. 1 Overall System View

The system configuration is shown schematically in Fig. 2. The system, conceived as a modular one, consists of the cabin module (1), the computer module (2), the vehicle model software module (3), the visual display module (4), the force-feel module (5) and the acoustic module (6).

2.2 CABIN MODULE

As shown by Fig. 3, the cabin module forms the structural nucleus of the system and is based on actual car hardware (Mercury Tracer, 1987). It simulates the cabin of a

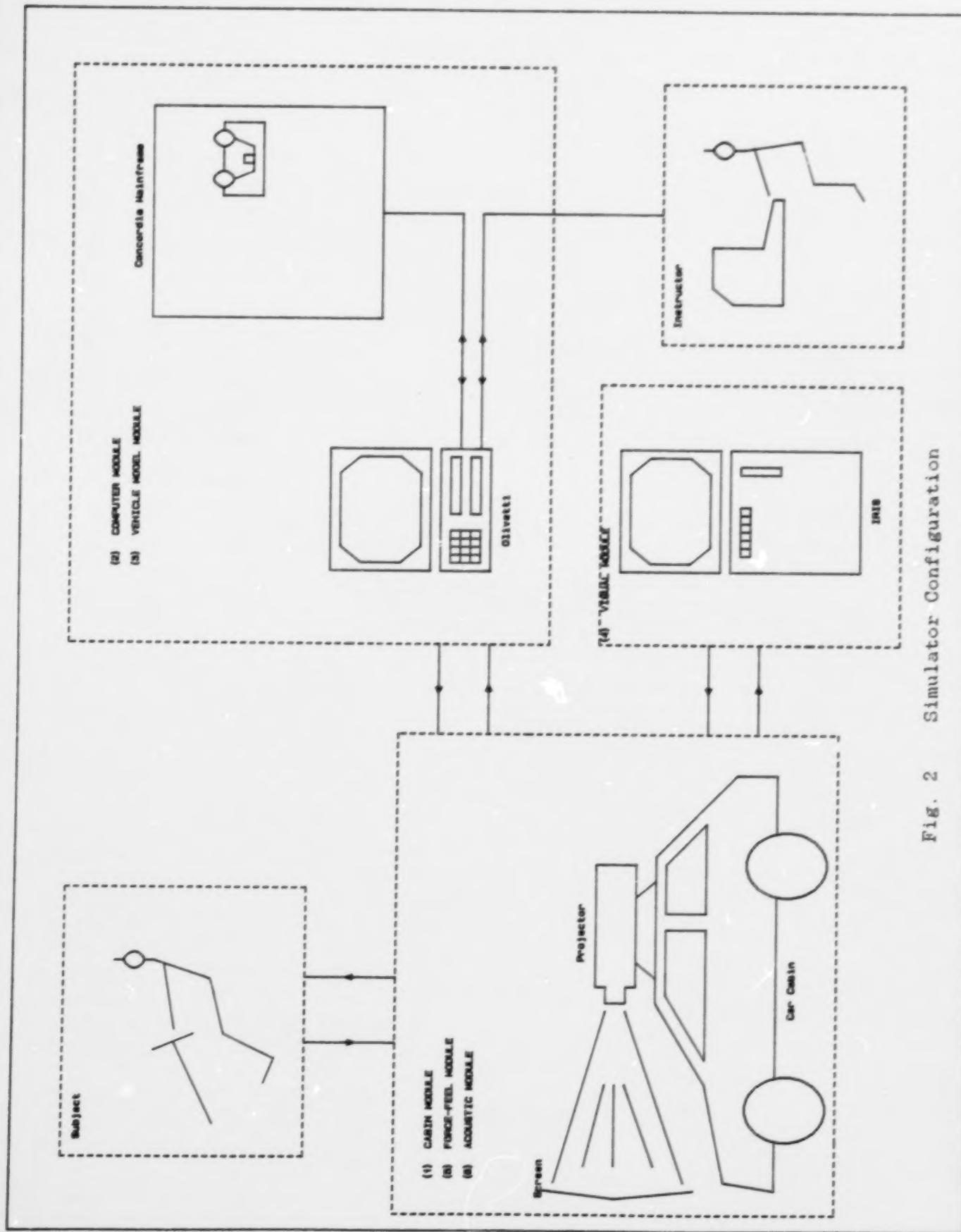
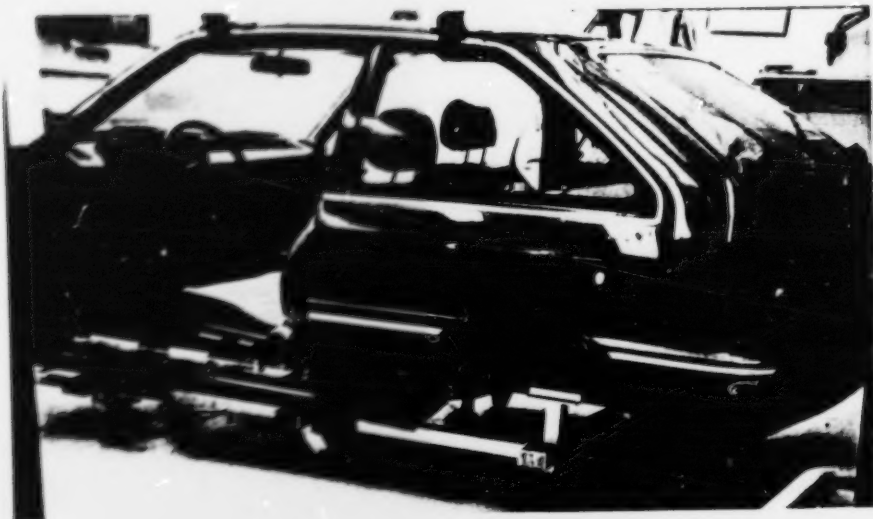
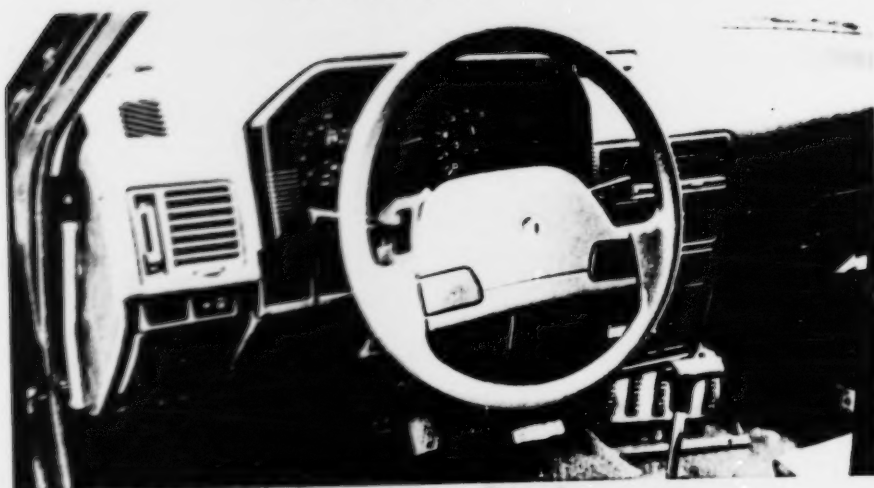


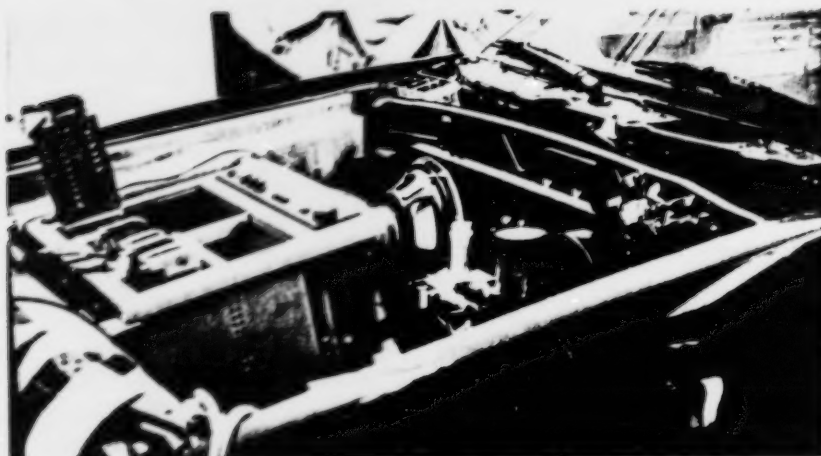
Fig. 2 Simulator Configuration



a) Side View



b) Instrument Panel



c) Engine Compartment with I/O circuitry

Fig. 3 Cabin Module

representative automobile. The automobile systems include all necessary controls as well as an instrumentation panel housing, basic driving instruments, indicator lights and switches. The cabin enclosure, seats and windshield contribute to a realistic representation of the car cabin. The speakers of the acoustic module are mounted inside the cabin enclosure. In addition, this module accommodates the interface circuitry and the visual and force-feel modules. For ease of system transportability, the cabin can be separated in two parts along the car firewall.

Table 1, shown below, lists the car controls and instruments provided in the car module.

Table 1 - Car Module Controls and Instruments

INPUTS	TYPE	SENSOR
Steering Wheel	continuous	optical shaft encoder
Gas Pedal	continuous	RVDT
Brake Pedal	continuous	pressure transducer
Transmission Stick	6 position	RVDT
Hand Brake	ON/OFF	Switch
Key	ON/OFF	Switch
Low beam	ON/OFF	Switch
High beam	ON/OFF	Switch
Flashers	ON/OFF	Switch
OUTPUTS	TYPE	DRIVE
Speedometer	continuous	DC Motor
Tachometer	continuous	AC Signal
Fuel Gauge	continuous	Galvanometer
Temperature Gauge	continuous	Galvanometer
Oil Light	ON/OFF	Switch
Alternator Light	ON/OFF	Switch
Brake Light	ON/OFF	Switch

2.3 COMPUTER SYSTEM MODULE

This module consists of computer hardware, system software and instructor facilities software.

2.3.1 Computer Hardware

As seen in Fig. 4 (refer also to Figs. 2 and 3c) the core of the computer system is formed by any IBM PC family computer (or equivalent - in this case an Olivetti M24) personal computer, which acts as the host processor and runs the vehicle model software. The IBM PC also serves as the instructor's facility. Furthermore, the host unit communicates with the cabin module hardware and the acoustic module via the

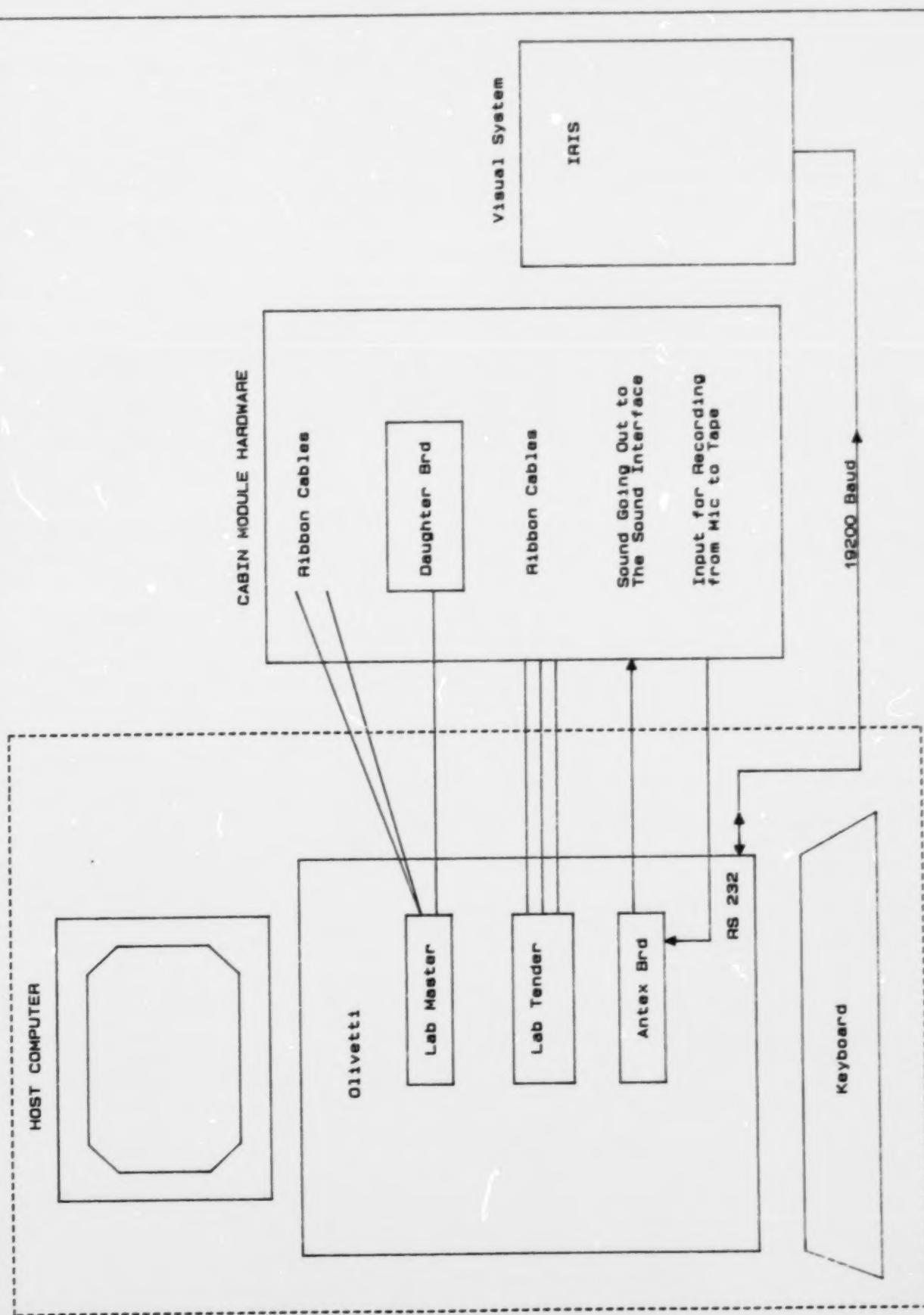


Fig. 4 Computer System Hardware

SCIENTIFIC SOLUTIONS LABMASTER interface unit. Also, a high speed serial link with the IRIS 3120 graphics workstation provides the vehicle position and attitude information required for the interactive visual scene generation. During the system development the IBM PC was also linked to the Concordia's mainframe CDC computer system, used for the initial vehicle model software development.

2.3.2. System Software

The system software, written in PASCAL serves the following:

- : handling of inputs/outputs (I/O's) between the host computer and the cabin module hardware and the acoustic hardware.
- : communication between the host computer and the IRIS graphics station.
- : collision detection
- : maintaining a crude model for system debugging and testing
- : providing hardware debugging tools

2.3.2.1 Hardware Interfacing

On the host computer side all I/O's to the Car Simulator models is performed through three boards: SCIENTIFIC SOLUTIONS LABMASTER and LABTENDER interface units and the ANTEX VP 600 voice processor. The LABMASTER and LABTENDER are equipped with analog to digital converters (A/Ds), digital to analog converters (D/A's) and Digital-In/Digital-Out ports. The D/A's are used to drive the various analog devices in the car simulator. These include the speedometer, the tachometer, and the fuel and temperature gages. The A/D's are used to read the values of the gas pedal, the brake pedal, the steering wheel, and the transmission stick. Digital values read from the car are: the key position, the turn signal arm position, the hand brake, and the low and high beam headlight position. Digital values sent to the car are: the oil light, the battery light, and the brake light (refer also to Table 1).

The ANTEX voice processor is used to interface with the sound hardware of the car simulator.

2.2.3.2 Communication With IRIS

Since the vehicle dynamic model is implemented on a different computer than the one drawing the graphics, some sort of communication is needed between the host computer and the graphics computer. This communication is accomplished through a standard serial RS-232 port.

When the IRIS is ready to draw an image it sends a prompt character to the host computer. The serial port on the host side interrupts the running of the model and a service routine is run which sends the six position coordinates to the IRIS. In this manner each computer can run independently and at its maximum iteration rate.

To ensure the correctness of the data sent over to the IRIS, once each iteration, the host computer copies the parameters into a temporary buffer where the interrupt service routine is guaranteed to find the data in its entirety. During the process of copying the parameters over the interrupts are masked to prevent an interrupt from occurring part way through this process.

2.3.2.3 Collision Detection

In order to minimize the communication between the IBM PC host and the IRIS workstation, the collision check model has been accommodated by the host computer. However, the host had to be made familiar with the shape of the IRIS's world. The 150m by 150m IRIS world grids have been transferred to the host with resolution grids of 1m by 1m, each described by two bits (road, ground, pothole, solid object). Additional two bits per grid are used to describe the surface texture (slippery, normal, rough, very rough).

The actual collision detection is done by passing the car's coordinates for each wheel, and for the front and back centre to a routine which returns the contents of the world at that location, be it road, pothole, ground or solid object. Also the texture of the road is returned at the wheels coordinates. The model then interprets this information.

Since the car is often moving faster than one meter per iteration, all the ground between the last coordinates and the new coordinates must also be checked for collision.

This system allows both computers to be aware at all times of the contents of the world. Also it provides inputs to the dynamic model such as hitting a sidewalk or driving onto a slippery section of road such as ice.

2.3.2.4 Crude Vehicle Model

For debugging and testing purposes a simplified engine and dynamic model was implemented. This allowed for the system software, hardware, and graphics to be tested immediately while the full engine and dynamic model was being developed.

2.3.2.5 Hardware Debugging Tools

Certain hardware debugging tools are provided by the system software. These were implemented to facilitate the debugging of the various hardware components in the development stage and also for maintenance and trouble shooting.

Four debugging functions are offered: ramps to galvanometers, lock values on galvanometers, digital input / digital output, and test analog to digital. These four functions allow all the I/O channels to be exercised independently of the model.

2.3.3 Instructor Facilities Software

The host computer allows the instructor to interact with the car simulator while the model is being run. It provides several facilities for the instructor to monitor the actions of the person driving while updating the environment they are driving in.

Displayed on the screen in a graphical representation is the position of the car controls such as the gas pedal, the brake pedal and the transmission. Also displayed are the speed and engine rpms. Headlight and brake light status are also displayed.

The instructor also has several controls over the world. They can start and stop the traffic or even eliminate it completely. They can also toggle between day and night scenery.

Another option is to switch into map mode. In this mode, instead of displaying the view from the drivers seat, a bird's eye view is shown of the whole world. The instructor can now see the location of the car in the world and move the car using the cursor keys on the keyboard.

An evaluation function is supplied which displays information about the driver's performance. This function can be configured to any variable monitored by the system.

2.4 VEHICLE MODEL SOFTWARE

The vehicle model software, written in FORTRAN determines the vehicle movements as well as the parameters of the car engine in response to the driver's control inputs. The outputs of the vehicle model then in turn determine the various outside world cues (visual, sound, force-feel, instrument readings, etc.) presented to the driver.

2.4.1 Model Concepts and Limitations

The model software configuration reflects the modular design concept of the simulator system. As shown in Fig. 5, the vehicle model is organized in the following self-contained homogeneous blocks:

- : engine (1)
- : transmission (2)
- : wheel-tire system (3)
- : steering system (4)
- : forward movement (5)
- : lateral movement (6)
- : attitude (7)

Each of the above blocks represents a well defined function and in most cases may be examined, modified and calibrated as an independent unit.

Active forces and moments are calculated using the power-torque characteristics of the Mercury Tracer engine, combined with thermodynamic algorithms and computing procedures already used in modeling of aircraft internal combustion engines.

Reactive forces and moments are calculated using well known road-tire friction factors and retested side forces computation procedures.

Angular and linear velocities are calculated as a result of Newton's First Law application to the engine, wheels, and car system. Each differential equation is solved either with the state-space method or with a first order numerical integration. The six degrees of freedom multimass car system is decoupled in three subsystems:

- : the forward movement of the rigid car mass,
- : the yawing and lateral movements of the rigid car mass,
- : the pitching, rolling and vertical movements of three interacting mass systems, car sprung mass and axles.

In order to provide acceptable computation iteration rate, of some 10-15Hz the pitching, rolling and vertical movements calculations were not implemented. However, the mathematical algorithm to solve this three degrees of freedom subsystem is already provided as a part of this package. Furthermore, the vehicle model does not compute co-ordinated reverse driving maneuvers. Also, no provisions are made to take into account sloping roads.

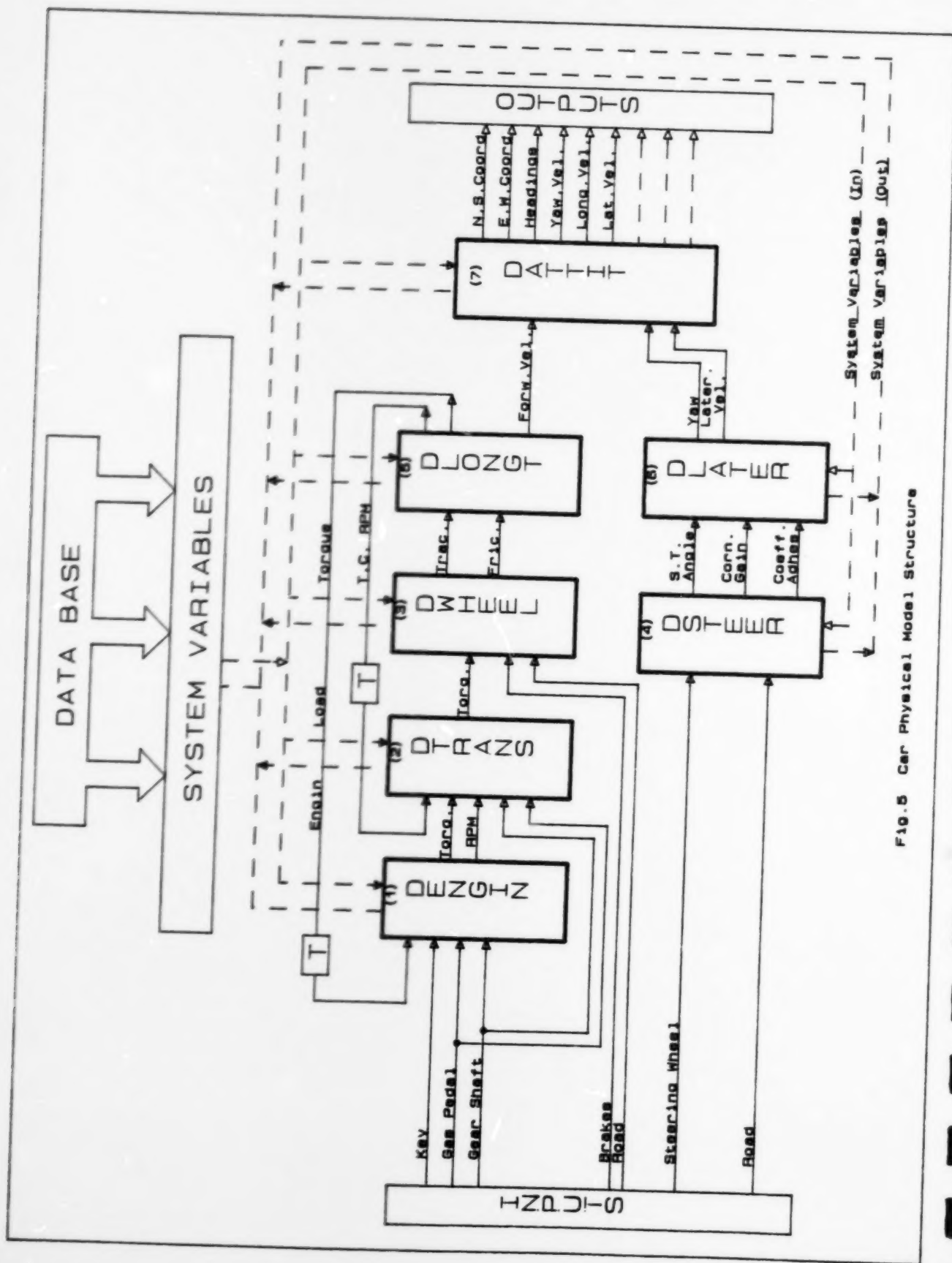


FIG. 5 Car Physical Model Structure

2.4.2 Model Structure

Engine subroutine computes the powerplant torque and rpm in response to gas pedal, starting key and gear shaft positions.

Transmission subroutine determines the torque transmitted to the differential drive shafts in response to engine brake torque, engine rpm, gas pedal and gear shaft positions.

Wheel-Tire System subroutines calculates the traction and resistive load in response to brake pedal position, differential drive shaft torque and road conditions signals.

Steering System subroutine determines the geometric steering angle, the cornering gain of each wheel and the side coefficients of adhesion in response to steering wheel position.

Forward Movement System subroutine calculates:
: forward velocity with respect to air in body axes
: forward velocity with respect to ground in body axes
: rpm of each wheel
: torque converter shaft rpm
: engine shaft reactive torque

The subroutine inputs are brake pedal position, differential drive shaft torque and road conditions.

Lateral Movement System subroutine computes the lateral and yawing velocities with respect to the body axis system in response to steering angle, cornering gain and tire coefficient of adhesion of each wheel.

Attitude System subroutine transforms all components of the linear and angular velocities from body axis system to fixed ground axis system. The subroutine is also set to calculate pitching, rolling and vertical velocity components. This portion, however, is not implemented and these velocity components are set to zero.

The subroutine inputs are:
: forward velocity with respect to body axis system
: lateral velocity with respect to body axis system
: yawing velocity with respect to body axis system

Several off-line subroutines are also employed, calculating the torque and gear ratio relationships and the state-space coefficients.

2.5 VISUAL DISPLAY MODULE

This module, which generates the car simulator visual cues, includes both hardware and software.

2.5.1 Visual Hardware

As shown in Fig. 6, (refer also to Fig. 2) this module hardware consists of the IRIS 3120 graphic station driving the ELECTROHOME ECP CAD/CAM colour video projector mounted on top of the cabin module. The video projector delivers the visual scenery to a screen positioned in front of the cabin module. The IRIS station is linked to the IBM PC host computer by a high speed serial link.

2.5.2 Visual Software

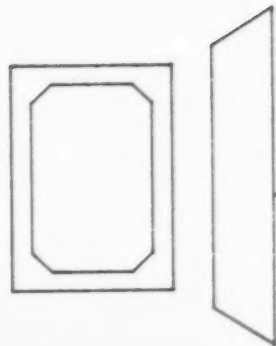
This section describes the algorithms and techniques used to display a three dimensional scene consisting of static terrain and a few moving objects. The scene is displayed from a moving point of view with hidden surfaces removed. The methods described have been used to generate a through-the-windshield view in real-time.

The goal was to generate a real-time (10-15 Hz) visual scene representing what a driver would see while driving through cities and highways. Examples of typical scenes are shown in Fig. 7. The major limitation of this system is reflected in the complexity of the scenes. Due to the limited computing power available in the visual computer, some trade-offs had to be made. While it is a simple matter to add more detail to the visual scenes, this would severely degrade the dynamic performance, because the IRIS can only display a finite number of polygons per second. Thus a balance had to be achieved between scene complexity and real time performance.

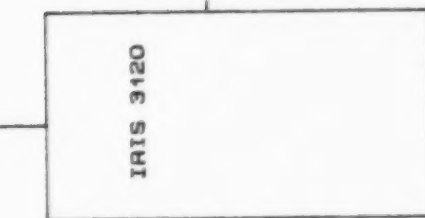
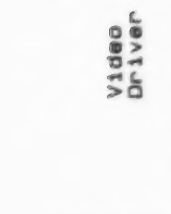
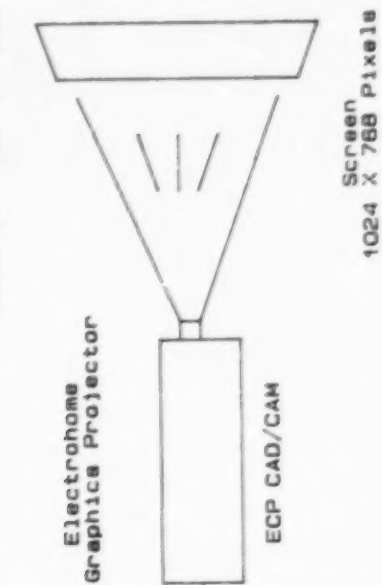
The approach to the visual software development was based on the fact that only a small portion of a large static database representing terrain features along with several moving objects is viewed. The method of Binary Space Partitioning Trees (BSP trees) has been adopted as a basis for the simulator visual software. The BSP method is useful for fast generation of static scenes viewed from different positions. It has been modified, however, to accommodate moving objects, which are inserted into the BSP tree 'on-the-fly' at every frame.

Also, since only small part of the visual database is being viewed at any particular time, the database was divided into 150m x 150m grid squares, each square representing a typical portions of the city or highway scene. Then a BSP tree was built for each square. Every iteration, the moving objects are added to their

Graphics Workstation



Field of View: 80 deg



Position Data
RS-232
19200 Baud

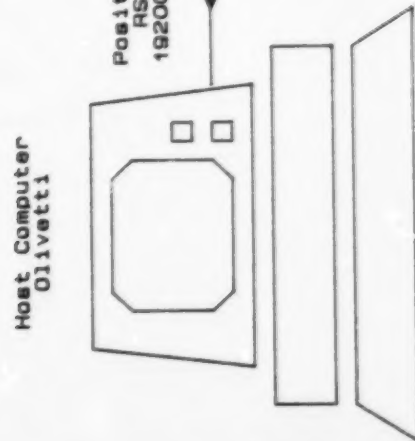
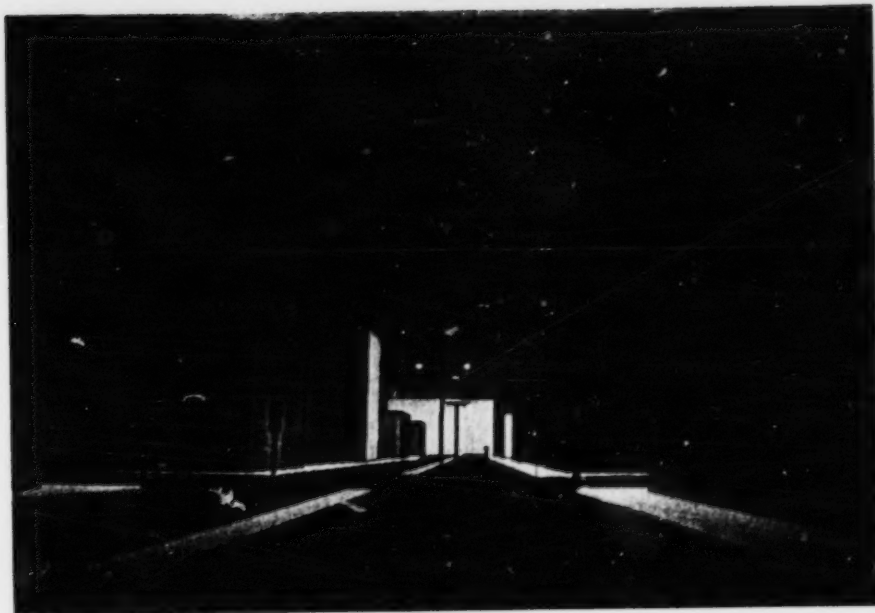


Fig. 6 Visual System

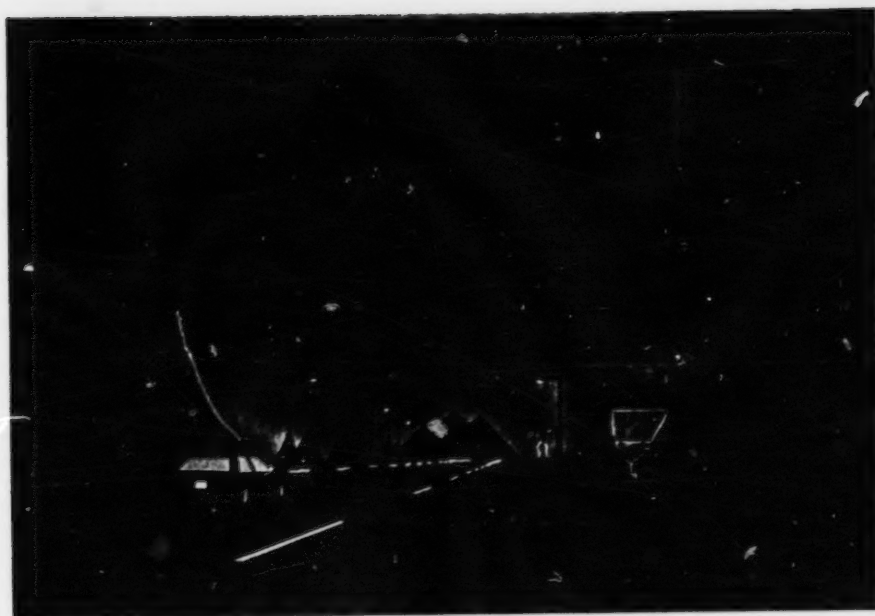
respective squares, and only the grid squares that are in the field of view are drawn.

The visual software system can be split into two main sections: database pre-processing, and scene generation.

The pre-processing, which includes the definition of each grid square and the definition of the entire database, can take



a) City Scene



b) Highway Scene

Fig. 7 Typical Visual Scenes

up to a few minutes and is done only at start up, which decreases the real-time computing requirements of the system.

The scene generation, carried out in real time, includes three tasks. The first task is to determine which grid squares are within view, sorted from farthest to nearest. Next, moving objects are added to the BSP trees of only the visible grids. Lastly, each of these grids is drawn by traversing their respective BSP trees. To accommodate moving objects (cars) within the visual scene, it was assumed that a moving object is constrained to move within the boundaries of the road, thereby making it simpler to determine where to insert each car in the BSP tree.

2.6 FORCE-FEEL MODULE

The force-feel system involves the generation of realistic steering wheel and control pedal forces. The steering wheel force is generated by set of centering springs, the gas pedal force is also generated by a spring, whereas the brake pedal force is simulated by a hydro-pneumatic accumulator with adjustable stiffness (see Fig. 8).

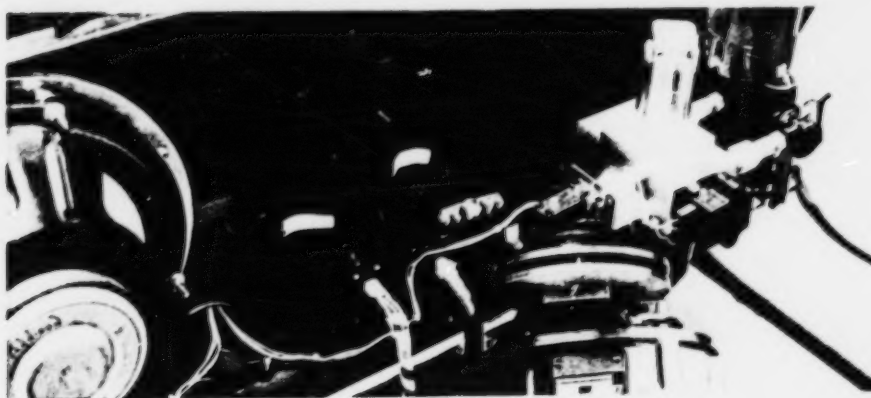


Fig. 8 Force-Feel Module

2.7 ACOUSTIC MODULE

This module, which provides representative car driving acoustic cues, includes both hardware and software.

The acoustic hardware, is shown schematically in Fig. 9. The input stage consists of ANTEX VP 600 sound board for digitized recording, sounds, a tape deck for sound authoring, a custom built engine sound driver board and a custom built public address system for communication with the subject. The volume control is provided by custom built volume control board. The output stage consists of a custom built stereo mixer, NAD 3020e audio amplifier and a set of speakers.

Various driving sounds such as skidding noise or crash sound are stored digitally by the ANTEX voice processor board. These sounds are recalled and played back under the control of the acoustic software model residing in the host computer. The acoustic model communicates with the ANTEX board via one of the host computer interrupts. When the ANTEX is started it is filled with sound data and is then left on its own. The host computer therefore can continue running the model. When the ANTEX needs more data it interrupts the host computer's CPU which runs a service routine which refreshes the board. In this manner the function of the ANTEX board is transparent to the modelling software.

Engine sounds are generated directly from the tachometer AC drive signal after an appropriate processing in a specially designed filter.

In this manner both engine and driving sounds are heard by the user with a limited burden to the host system software.

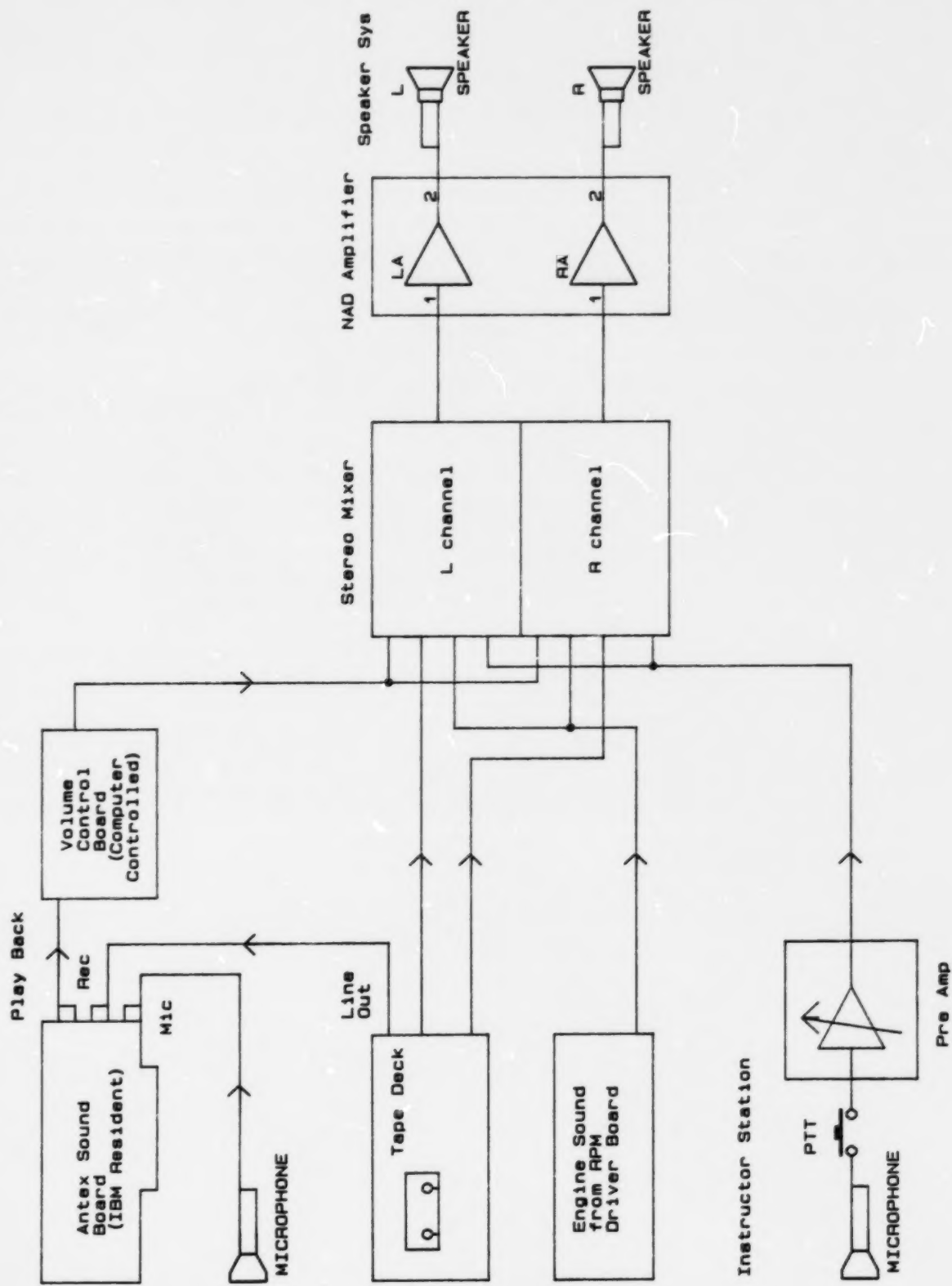


Fig. 9 Acoustic Hardware

3. SUMMARY OF RESULTS AND CONCLUSIONS

The project work resulted in a successfully completed working 'proof-of-concept' automobile simulator system. However, due to the budget limitations the project goals had to be redefined somewhat.

The system development was curbed in the areas of the visual system, force-feel system, instructor facilities, and the assessment and training protocols. Accordingly, only a front visual system was developed and no attempt made to carry out systematic visual cue effectiveness evaluation. The force-feel system of the steering wheel is a simple passive spring system. The instructor facilities are only very basic and not user-friendly. The development of even rudimentary assessment and/or training protocols was not attempted. However, in keeping with the reduced goals, the simulator system was conceived and built in such a way that future expansions and improvements are possible without having to change the basic structure of the system. For example, the expansion of the visuals to a full 'wrap-around' system can be accomplished by a relatively straightforward 'add-on' procedure of additional hardware and software. Similarly, the follow-up development of a comprehensive assessment and/or training procedure was anticipated by the system's capability of 'on-line' monitoring of all simulator physical variables.

4. RECOMMENDATIONS FOR FUTURE WORK

The simulator system limitations described in Section 3 were discussed throughout the project, particularly throughout its second year, with TDC officials. It has been concluded, that to ensure that the project fulfills its original goals, further R & D work will be necessary, through which the existing 'proof-of-concept' device will be transformed into a commercially viable system with practical use.

The areas, requiring further work are as follows:

- (i) Visual System
 - . perceptual optimization of the visual cues
 - . development of 'wrap-around' system
- (ii) Force-Feel System
 - . development of interactive force-feel for steering wheel
- (iii) Instructor Facilities
 - . development of more comprehensive, user friendly system
- (iv) Assessment System
 - . development of driving capability assessment system
- (v) Training System
 - . evaluation of the system suitability for driver training
 - . development of driver training system

